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EVALUATION OF RELATIONS BETWEEN POLLUTION ABATEMENT AND OPERATION OF WATER RESOURCES DEVELOPMENTS ON THE CUMBERLAND RIVER

Public Health Service
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INTRODUCTION

General.

Under date of August 29, 1952, the District Engineer, Nashville District, Corps of Engineers, Department of the Army, addressed a communication to the Officer in Charge, Ohio and Tennessee Drainage Basins, Public Health Service, Federal Security Agency, concerning the desirability of evaluating benefits to pollution abatement resulting from flow regulation at reservoir projects in the Cumberland River Basin. After further correspondence and a conference between District and Division representatives of the Corps of Engineers and Basin office and Environmental Health Center representatives of the Public Health Service, it was agreed that the Public Health Service, in cooperation with the Tennessee Stream Pollution Control Board, would study the available data and report on water resources developments as related to pollution abatement requirements.

Major water resources developments have been made in the Cumberland River basin within the past few years. Prior to that time the most important development consisted of a series of low-head navigation dams providing for navigation from the mouth of the river to about mile 331, some 140 miles above Nashville. Recently three dams have been constructed for the purposes of flood control, hydroelectric power generation, and conservation storage. These are Dale Hollow Reservoir on the

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Obey River, Center Hill Reservoir on Caney Fork, and Wolf Creek Reservoir on the main stem. At the present time, medium-head navigation and power dams are under construction at Cheatham and Old Hickory. These will replace existing navigation dams between Cheatham and Carthage, Tennessee. Future plans call for replacement of all low-head navigation dams below Cheatham. Other tributary storage reservoirs are also under consideration. The location of river developments pertinent to this report are indicated on the enclosed map and profile. Details of the developments and their operation, as related to this report, are discussed in subsequent paragraphs.

Under date of April 4, 1941, the Public Health Service prepared a memorandum report, at the request of the Corps of Engineers, concerning low flow-pollution abatement relations in the Cumberland River, with particular reference to benefits of regulated flows from the then proposed Wolf Creek Reservoir.

The Division of Sanitary Engineering of the Tennessee Department of Public Health made a study of the pollution and natural purification of the Cumberland River from Old Hickory to Clarksville during 1938 and 1939. The study was published in a report dated 1941.

A re-evaluation of relations between water resources developments and pollution abatement requirements is desirable because of changed conditions since the above reports were prepared. Developments under

construction and completed will materially change the flow and other characteristics of the river. For example, without Cheatham and Old Hickory Dams, intermittent water releases for power generation at Wolf Creek, Dale Hollow, and Center Hill Dams have been leveled off considerably before reaching Nashville by the retarding effect of the streambeds. Releases from Old Hickory will not receive an equivalent damping effect over the shorter distance involved. Changes in pollution loads and plans for abatement have also occurred since the above studies and reports were made.

Purpose of Report.

The purposes of this report are:

1. To present an analysis of treatment requirements at major key points of pollution under various assumed regulated flows and stream conditions which will be obtained after completion of Cheatham and Old Hickory Dams.

2. To make tentative conclusions on benefits obtainable under regulated flow conditions as a basis for considering water releases for pollution abatement in relation to other uses and to serve as a guide for further study.

3. To make a comparison between waste assimilating capacity of the river prior to water resources developments and that to be obtained with present developments, taking into consideration flow, stream characteristics, and temperature changes.

4. To make certain recommendations for further future studies where the current analysis is based on data or estimates considered inadequate as a basis for final conclusions.

Acknowledgments.

Conferences have been held with representatives of the Nashville District and Ohio River Division of the Corps of Engineers, of the Tennessee Stream Pollution Control Board, of the du Pont Company at Old Hickory in company with Tennessee representatives, and of the Tennessee Valley Authority. Information, data, and suggestions were furnished by the above agencies for use in the report.

The Corps of Engineers furnished information on the physical features of the river, dams, reservoirs, and power installations, and on operating characteristics of installed power facilities.

Representatives of the Tennessee Stream Pollution Control Board made available a copy of a special report entitled "Pollution and Natural Purification of the Cumberland River" by F. W. Kittrell, published by the Tennessee Department of Public Health in 1941; information on waste loads in the Nashville area; and other pertinent information. Also the Board made available data and information contained in the consulting engineers' report on proposed sewage disposal facilities for the City of Nashville.

Data were furnished by the du Pont Company, through the Tennessee Stream Pollution Control Board, on waste loads and on river temperatures

observed by the company over a period of time.

Information on characteristics of existing reservoirs in the Tennessee Valley and on the Gallatin steam plant was furnished by representatives of T. V. A.

Data from published records of the U. S. Geological Survey were also used in the report.

Acknowledgment is also given to representatives of the Environmental Health Center who assisted in analysis of reaeration characteristics of the stream under changed conditions, analysis of bacterial pollution effects, and in critical review of the report.

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CONCLUSIONS

1. Under critical flow conditions existing prior to any flow regulation in the Cumberland River, primary or equivalent treatment of sewage and industrial wastes in the Nashville area would have been insufficient to meet desirable water quality objectives. (Ref. section on basis for analysis.)

2. Provision of regulated flow to the extent that primary treatment would be sufficient to meet desirable objectives would have considerable value. The tangible value to the Nashville area, measured by savings in treatment costs, is estimated at $246,000 annually. Use of water for cooling at the new TVA steam plant at Gallatin, Tennessee, has tangible value but is not considered in this report. Another benefit from flow regulation for which no tangible value is assigned would be the provision of additional waste assimilating capacity in the lower river for future development and the promotion of recreation and fish and wildlife.

3. The reaeration capacity of the stream per unit of flow will be decreased as a result of the new main stem impoundments. A tentative estimate of this decrease has been made for purposes of this report. Verification by field investigation after completion of the reservoirs is recommended.

4. Based on experience to date, operation of reservoirs for power purposes will result in intermittent flows with considerable periods of

time during which no releases for power would ordinarily be made. Precise evaluation of the effects of such operation in relation to treatment of wastes discharged into impoundments is not possible on the basis of data available. Tentative conclusions are that average flows under such operation are not comparable to numerically equal uniform flows. Further study in coordination with the preceding conclusion is recommended.

5. With the limitations indicated above it is estimated that, during critical summer conditions, uniform flows of 1820 c.f.s. and primary treatment of wastes in the Nashville area will result in satisfactory water quality, assuming forecasted 1965 waste load conditions. A uniform flow of 1200 c.f.s. and primary treatment would be satisfactory under present load conditions. Lower temperatures during other seasons of the year would reduce flow requirements substantially below those indicated for critical summer months. The extent, if any, to which these minimum uniform flows could be reduced as a result of higher intermittent flows has not been determined.

6. Reservoir operation will not improve temperature conditions during critical periods. However, average temperatures will be lower and will prolong the period of lower flow requirements normally experienced during the colder months.

7. Low flow regulation would not eliminate the need for removal of bacteria from domestic wastes to protect public water supplies.

8. Assignment of benefits to pollution abatement resulting from construction and operation of water resources developments in the Cumberland River is dependent on the extent to which actual operation will be compatible with pollution abatement needs. The extent to which operation can best meet the needs of the various uses is a matter for consultation between interested Federal, State, and local interests. It is considered that additional field investigation and analysis upon completion of the projects would provide an essential part of data needed as a basis for final decisions.

PRESENTATION OF DATA

General Description of the Area.

The Cumberland River has its headwaters in southeastern Kentucky, flows in a southwesterly direction into Tennessee, then in a westerly direction across northwestern Tennessee, and, finally, re-enters Kentucky and discharges into the Ohio River about 15 miles above Paducah. This report is concerned with the section of the river affected by operation of Wolf Creek, Dale Hollow, and Center Hill multiple purpose reservoirs and by navigation and power dams at Cheatham and Old Hickory. The locations of these facilities are shown on the enclosed map. Principal sources of pollution for which abatement requirements may be affected by the above operations are located at Old Hickory, mile 216.8, and at Nashville between approximate mile points 176 and 194.

Installation and Operation of Reservoirs.

The Corps of Engineers has prepared a plan for development of the Cumberland River Basin water resources. Projects of the plan, and the status of each, are indicated in table A.

Storage available in Wolf Creek, Center Hill, and Dale Hollow Reservoirs provides the water for regulated flows. However, the pattern of flow past the Nashville area will be governed by operation of Old Hickory and Cheatham during controlled low flow periods. Other principal effects at Nashville from the main storage reservoirs are related to temperature. There are other reservoirs in the comprehensive plan

Table A
Projects in the Corps of Engineers
Plan for the Cumberland River
(Data from the Corps of Engineers)

Project	Location of Dam	Status
Wolf Creek Reservoir	Cumberland River River Mile 460.9	Completed
Dale Hollow Reservoir	Obey River River Mile 7.3	In operation. Two power units installed. Addition of third unit in progress.
Center Hill Reservoir	Caney Fork River Mile 26.6	Completed
Old Hickory Lock and Dam	Cumberland River River Mile 216.2	Under construction
Cheatham Lock and Dam	Cumberland River River Mile 148.7	Under construction
Stewarts Ferry Reservoir	Stones River River Mile 6.8	Authorized
Three Islands Reservoir	Harpeth River River Mile 6.3	Authorized
Reesview Reservoir	Red River River Mile 17.4	Authorized
Celina Dam	Cumberland River River Mile 385.7	Authorized
Carthage Dam	Cumberland River River Mile 313.5	Authorized
(1)Lower Cumberland Reservoir	Cumberland River River Mile 30.5	Proposed (Project authorization pending)
Helenwood Reservoir	S. Fork of Cumberland River River Mile 74.9	For future consideration
Devils Jumps Reservoir	S. Fork of Cumberland River River Mile 46.4	For future consideration
Laurel Reservoir	Laurel River River Mile 1.7	For future consideration
Rockcastle Narrows Reservoir	Rockcastle River River Mile 9.0	For future consideration

(1) Recommended by the Corps of Engineers in lieu of the authorized Dover and Kuttawa low lift navigation locks and dams at miles 100.1 and 32.2, respectively. Locking facilities would be provided.

not yet completed or under construction. Conceivably, provision of additional storage above Nashville would increase the average flow during low flow periods. However, conclusions in this report are based on assumed flow conditions applicable to operation of both existing and future reservoirs. Construction of the Lower Cumberland Dam and subsequent operation could materially change the characteristics of the stream related to pollution abatement in the lower part of the river. Relative insignificance of pollution in the lower river at this time does not warrant further consideration in this report.

Pertinent data for river development projects completed or under construction are presented in table B.

After discussions with Corps of Engineers representatives, it was decided to consider a range of flows within reasonable limits of expected operation of units for power generation and to cover the range of maximum benefit for pollution abatement. Normally it would be expected that operation of power units during low flow periods for peak power purposes would be intermittent in character and limited by the capacity of the generating units and availability of water. Table B indicates that capacity through each unit at Old Hickory under normal head would be about 7500 c.f.s. It was advised by Corps of Engineers representatives that the units could operate efficientiy at considerably lower flows. As a basis for consideration it was assumed that critical low release conditions desirable

Table B

Pertinent Data for Reservoir Projects Completed or Under Construction
(Date furnished by Corps of Engineers)

Feature	Wolf Creek	Dale Hollow	Center Hill	Old Hickory	Cheatham
Reservoir					
Operating levels:					
Top Flood Control Pool	760	663	685	450(1)	
Top Power Pool	723	651	648	445	385
Minimum Pool Full draw down	673	631	618	442	382
Storage (Ac. Ft.)					
Flood Control	2,094,000	353,000	762,000	125,000(1)	-
Power	2,142,000	496,000	492,000	63,000	19,800
Conservation	1,853,000	857,000	838,000	357,000	84,200
Total	6,089,000	1,706,000	2,092,000	545,000	104,000
Power Installation					
Number Units	6	3	3	4	3
Unit Capacity, KW	45,000	18,000	45,000	25,000	12,000
Total Installed Cap., KW	270,000	54,000	135,000	100,000	36,000
Total Plant Cap. at Normal Head (c.f.s.)	22,000	5,300	11,000	30,000	22,000
Estimated Cost (1952 Base)	82,700,000	26,193,000	44,978,000	51,900,000	32,200,000

(1) Based on surcharge operation.

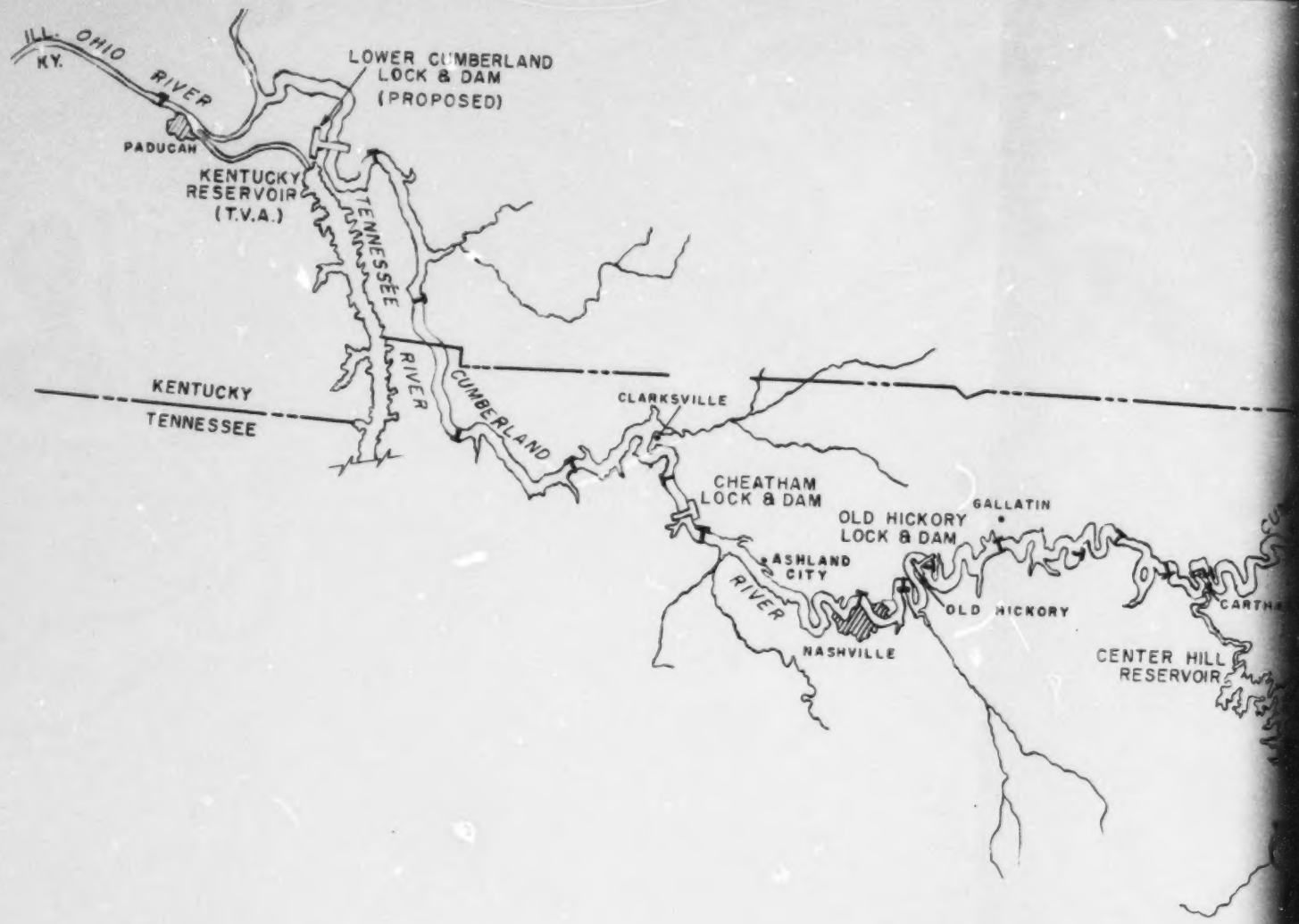
from the standpoint of power generation would be represented by average daily flows on week ends of 1000 c.f.s. with release through the turbines occurring over an 8 hour period and by average daily flows during week days of 2000 c.f.s. occurring over about 10 hours. Reference is made to the analysis following for various flow conditions which have been considered.

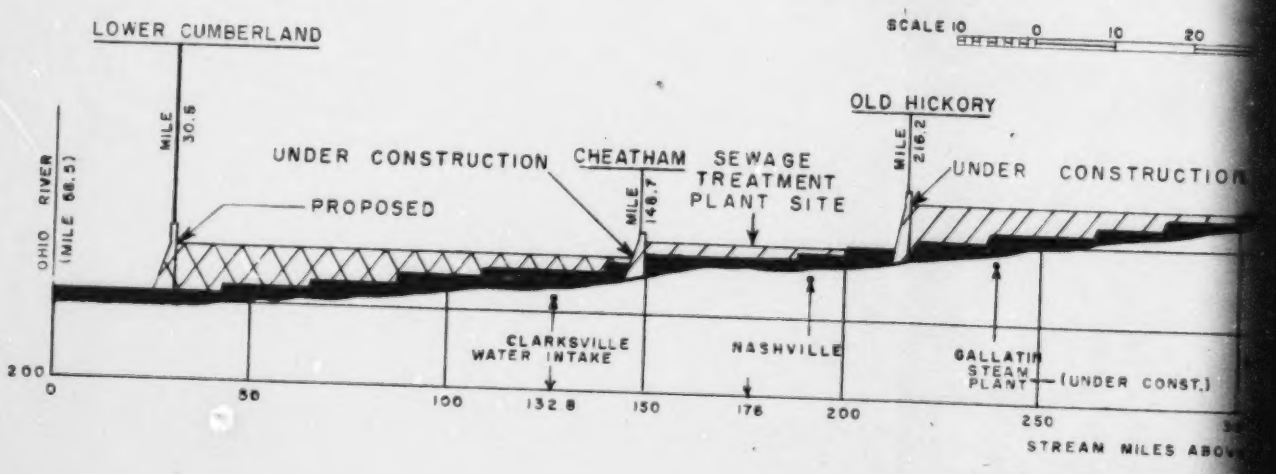
Location of existing features and those under construction are shown in plan and profile on figure No. 1. The profile indicates the low head navigation dams being replaced. Figure No. 2 is an enlarged profile of the section below the proposed location of the Nashville outfall sewer. Figure No. 3 shows a comparison between velocities under existing conditions and with Cheatham Dam in place.

Water Uses.

Carthage, Lebanon, Gallatin, Hendersonville, Old Hickory, Madison, Nashville, and Clarksville obtain water supplies from the Cumberland River. Ashland City obtains its water supply from a small tributary near its junction with the Cumberland River. This intake will be in the pool of Cheatham Dam after impoundment. The supplies at Madison, Nashville, Ashland City and Clarksville are located below major sources of pollution. Industrial water supplies are obtained directly from the river and through municipal systems. Future industrial growth is dependent on an ample supply of water having satisfactory quality.

In the public hearings conducted by the Tennessee Stream Pollution

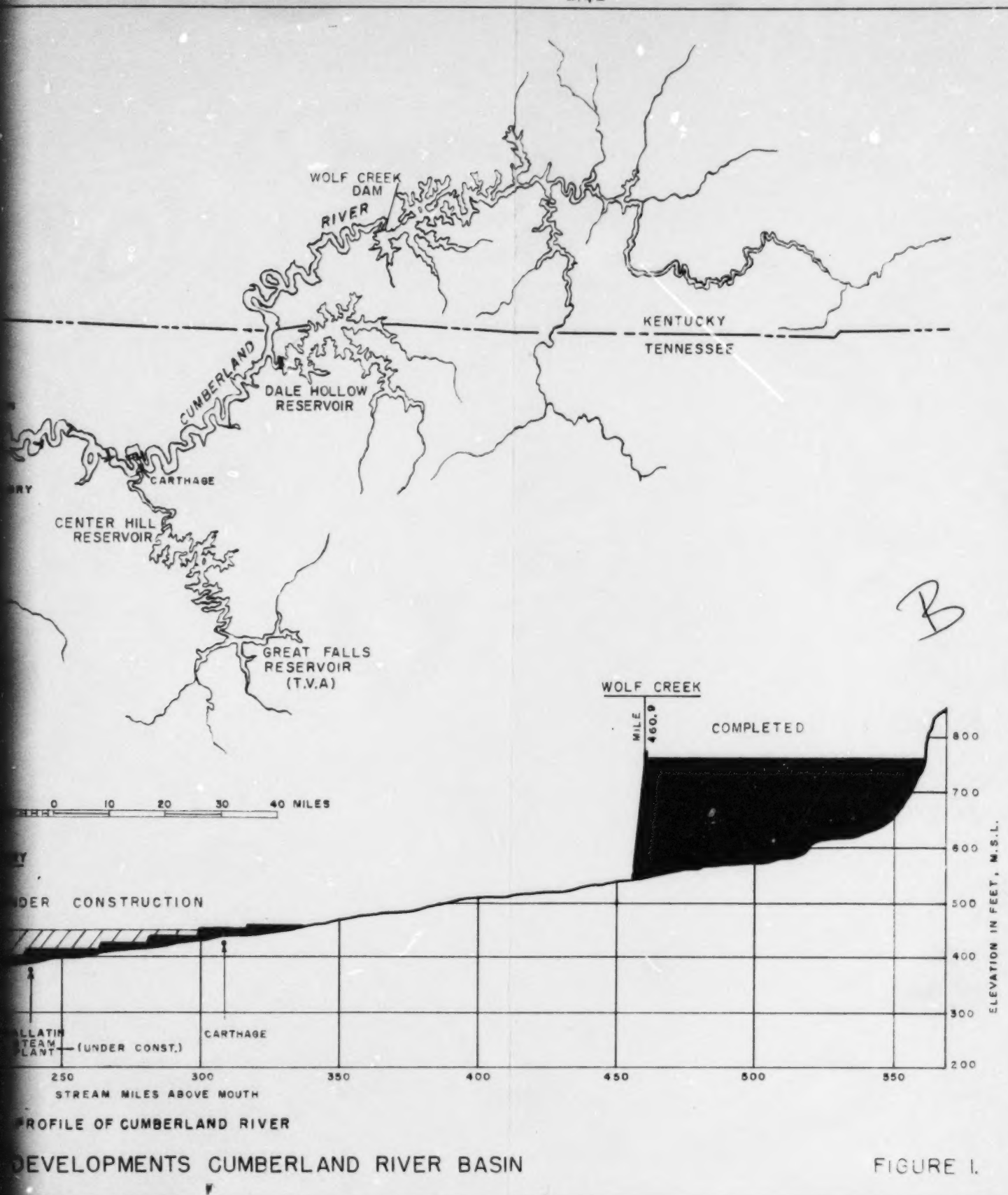




PROFILE OF CUMBERLA

A

WATER RESOURCES DEVELOPMENTS



PROFILE OF CUMBERLAND RIVER

DEVELOPMENTS CUMBERLAND RIVER BASIN

FIGURE I.

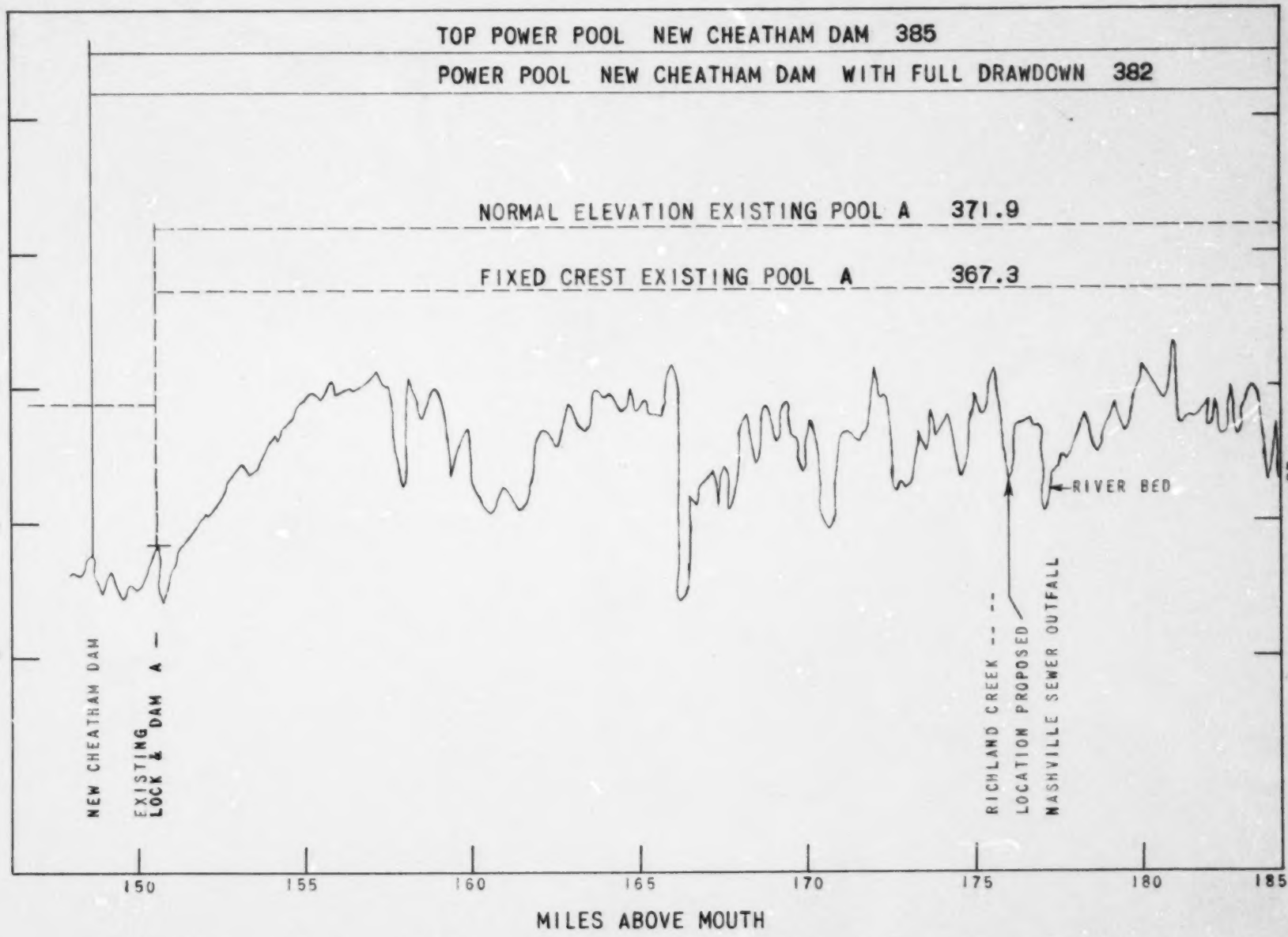


FIGURE 2

CHANGE IN POOL DEPTH — CUMBERLAND RIVER ABOVE CHEATHAM DAM

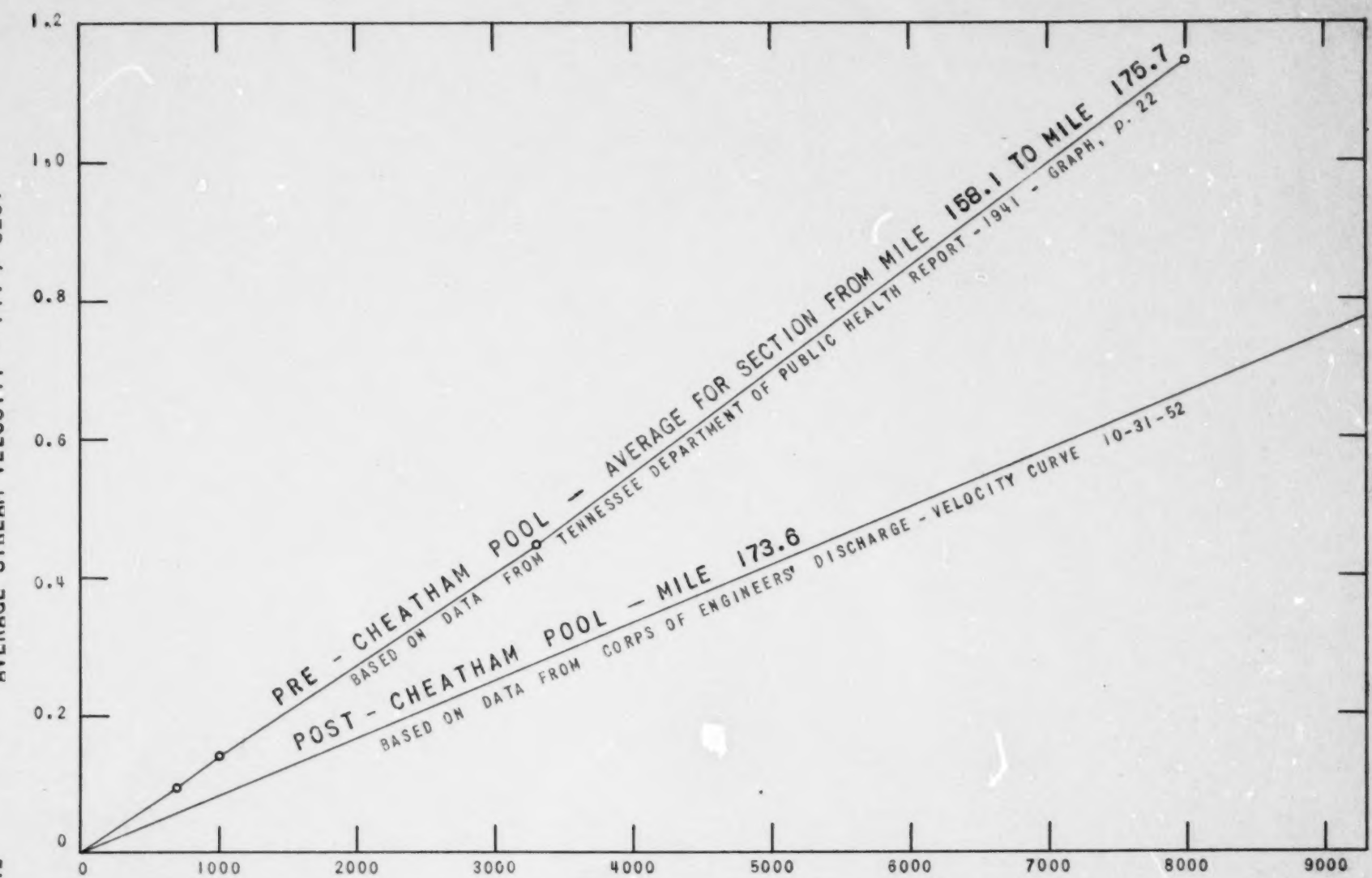


FIGURE 3

VELOCITY - DISCHARGE CURVE - CUMBERLAND RIVER (CHEATHAM POOL)

Control Board in 1951, it was recommended that the quality of water in the lower Cumberland River be maintained in a condition suitable for public water supplies, industrial uses, and recreational uses, including fishing.

Pollution Loads.

Principal sources of pollution are the du Pont plant at Old Hickory and the City of Nashville, including industries within and adjacent to the City. There are other smaller sources of pollution along the main stem of the Cumberland and its tributaries. They do not affect the conclusions of this report and are not considered further.

Estimates furnished by du Pont representatives show a five-day bio-chemical oxygen demand of about 16,000 pounds (about 94,000 population equivalent). Information furnished through the Tennessee Stream Pollution Control Board show the wastes to have the following additional characteristics:

Quantity	28.9	m.g.d. (24 hours)
Color	6	p.p.m.
pH	2.9	
Zinc	4.4	p.p.m.
Sulphates (as SO_4)	1138	p.p.m.
Acidity (as H_2SO_4)	122	p.p.m.

Sewage and industrial wastes from Nashville are now discharged untreated to the Cumberland River or near the mouth of tributaries over

a stretch of about 18 miles. Present plans of the City provide for interceptors which will collect sewage for treatment at about mile 176.

The sewage and industrial waste loads from Nashville are estimated to have a population equivalent at present of about 308,600. The population equivalent attributed to industrial wastes is about 141,900 and to sewage is about 166,700. Additional studies would be needed to make a precise determination of the loads. The above estimates are considered sufficiently accurate for the purposes of this report.

The Consulting Engineers' report for the City of Nashville, referred to previously, estimated that the 1965 sewage waste load would have a population equivalent of about 285,000 and the industrial waste load was estimated at 192,000 population equivalent, a total of 477,000.

Based upon an anticipated minimum daily flow of 2000 c.f.s. at Nashville, sewage treatment plans prepared for the city by their consultants, providing for primary treatment only, were approved by the Tennessee Department of Health on June 7, 1948. Under these conditions it is assumed that the above loads will be reduced by 35 percent.

Stream Flow Data.

Stream flows under regulated conditions have been discussed above in connection with operation of power plants and are further considered under the analysis later in the report.

Data have been obtained from U. S. G. S. records on flows under

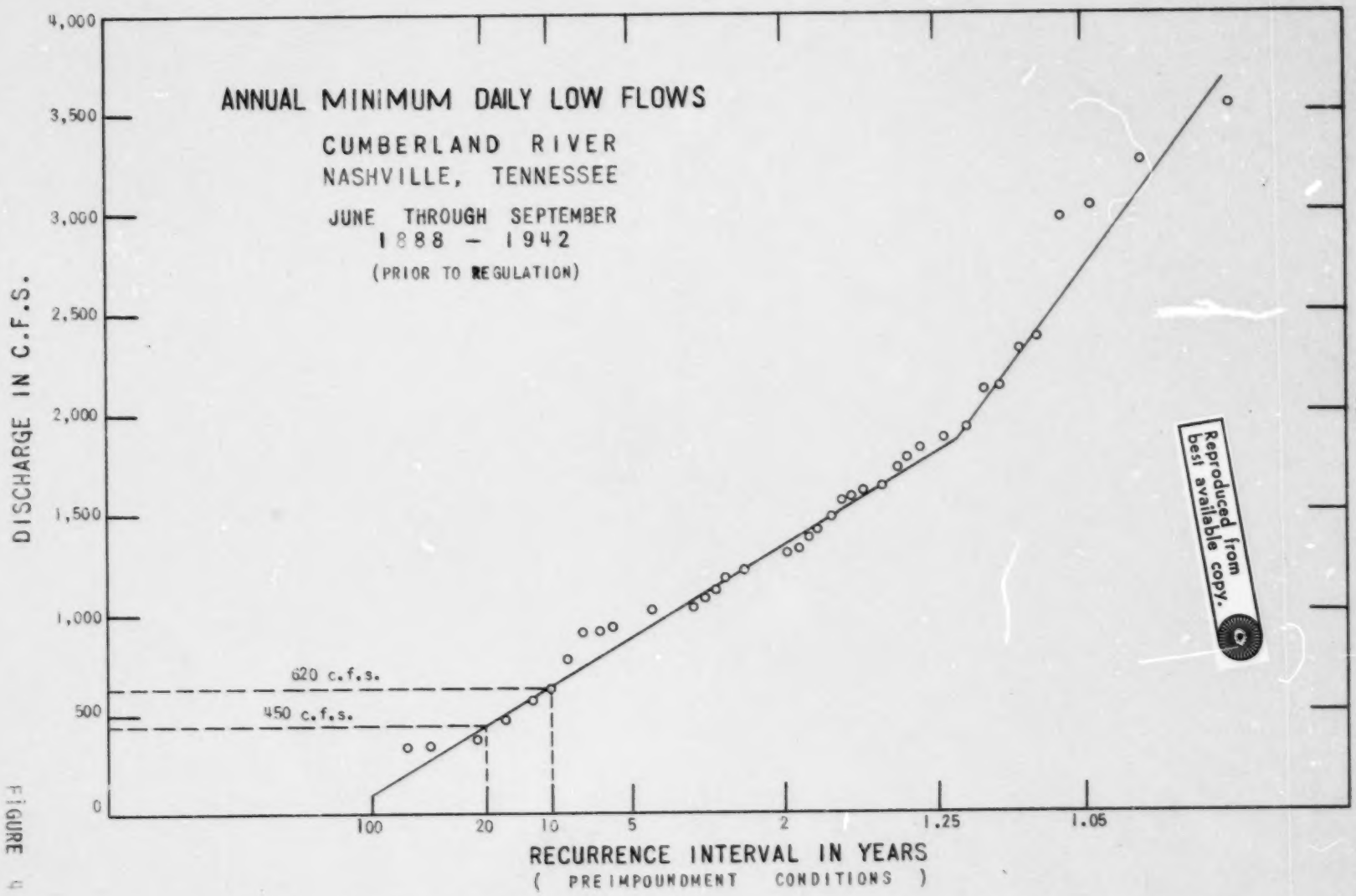


FIGURE 4

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conditions prior to impoundment and regulation. These data are summarized on the low flow frequency curve, figure No. 4. The curve shows that, during the warm season months of June, July, August and September, average daily flows of 450 c.f.s. or less and 620 c.f.s. or less could have been expected with a recurrence interval of twenty years and ten years, respectively, under preimpoundment flow conditions. These periods of recurrence are in the range ordinarily considered in design of waste treatment facilities.

Self Purification Characteristics prior to Major Water Resources Developments.

Reference has been made previously to a report entitled "Pollution and Natural Purification of the Cumberland River" published by the Tennessee Department of Public Health in 1941. Numerous stream analyses served as a basis for estimating the reaeration characteristics of the river and the deoxygenating characteristics of the applied waste load. The report estimates that these characteristics are reflected by values of reaeration and deoxygenation coefficients, as used in the Streeter formula, of 0.150 and 0.100, respectively, at 20° C.

Changes in Stream Conditions from Former to Proposed Conditions.

The new Cheatham pool will replace existing low head navigation dams. As a result, under low flow conditions the river will be deeper and more sluggish in the section receiving the Nashville wastes. The comparative depths and the comparative velocities at various flows are shown on

figures 2 and 3, respectively. The significance of these changes with respect to the self-purification capacity of the stream is evaluated later under analysis of relations between water resources development and pollution abatement.

Flow patterns under post-impoundment and pre-impoundment conditions have been discussed previously.

Average water temperatures have been reduced because of storage of cold water in the reservoirs. Daily water temperature records at Old Hickory for the period January 1948 to August 1952, obtained from the du Pont Company, show that, by mid-summer, the average temperatures with reservoir operation approach those formerly experienced. In the spring and early summer months the present average temperatures are lower than those experienced before impoundment.

Temperatures in the river will be affected by the operation of the Gallatin steam plant now under construction. The initial installation will be two power units. It is estimated by TVA that these units will have a total draft of 800 c.f.s. for condenser water and that the temperature of the water passing through the condensers will be raised about 12°F.

From the above considerations it is concluded that the summer temperature during critical low flow periods cannot be expected to be lower than those existing prior to impoundment. A temperature of 80° F. (26.7°C.) for critical summer months has been assumed for both

post-impoundment and pre-impoundment conditions.

It should be pointed out that if flows are sufficient to obtain satisfactory water quality with only primary treatment at Nashville, the lower temperatures will be beneficial in that lower flows will be required for a substantial part of the year. On the other hand, if adequate flows cannot be assured during critical periods, additional treatment facilities will be required regardless of reduced flow requirements during other periods.

ANALYSIS OF RELATIONS BETWEEN WATER RESOURCES DEVELOPMENT AND POLLUTION ABATEMENT

Basis for Analysis.

The analysis of the relationship between the reservoirs on the Cumberland River and pollution abatement is made on the basis of the data already presented and on the following considerations.

Water quality objectives should be consistent with the reasonable and necessary water uses. The water uses recommended as reasonable and necessary in the public hearings conducted by the Tennessee Stream Pollution Board for the Cumberland River below Nashville will be protected if the dissolved oxygen content is maintained at not less than 4 p. p. m., bacteria quality is maintained at a level consistent with the safety of public water supplies, and if wastes causing toxicity, tastes and odors are held to satisfactory limits. Insofar as the above objectives are concerned, the principal consideration with respect to flow regulation is the maintenance of desirable dissolved oxygen content. For purposes of considering the effects of waste from the du Pont plant at Old Hickory on the critical section below Nashville it has been assumed that the waste, as discharged to the river, will have a population equivalent of 75, 000. It is not inferred that the reduction by partial treatment indicated by the assumed value is adequate to provide a factor of safety for future development and reasonable use of the waters for similar purposes by others.

It is also assumed that arrangements for disposal of the du Pont wastes

will be such that, in relation to water releases from the power units at Old Hickory, the wastes will not travel downstream in concentrated slugs, and further, that toxic materials, indicated to be present in the waste, will be removed or so diluted that natural purification processes will not be inhibited.

It is assumed that the City of Nashville will proceed with present plans to collect, treat, and discharge its domestic and industrial wastes into the Cumberland from a single outfall located at mile 176, and that the effluent will be distributed to the stream in such a manner as to assure adequate mixing with the dilution water.

Assuming primary treatment of sewage and industrial wastes at the proposed Nashville sewage treatment plant and equivalent treatment for industrial wastes which may not be tributary to the plant, it is estimated that the waste load discharged to the river, based on 1952 load conditions, will have a population equivalent of about 200, 600. With secondary treatment and equivalent reduction of separate industrial wastes, the estimated load discharged would have an estimated population equivalent of 46, 300. Under forecasted 1965 load conditions the estimated waste load discharged, with primary treatment in a municipal plant and equivalent treatment of separate waste discharges, would be about 310, 000 and with secondary treatment about 71, 500.

Stream flows and stream purification characteristics under

pre-impoundment conditions, set forth under Presentation of Data, have been used in making a comparison between pre-impoundment and post-impoundment conditions.

The self-purification characteristics of the Cumberland River as it now exists have been determined from actual stream data by the Tennessee Department of Public Health. It is assumed that the de-oxygenation coefficient will not be changed significantly by the reservoirs now existing or under construction. As indicated above it is not expected there will be much change in critical summer temperature. On the other hand, it is expected that the reaeration coefficient will be substantially affected by the new stream conditions. The reaeration values for Cheatham Pool can best be determined by direct field study after completion of Cheatham Dam. On the basis of previous experience in other impounded streams of similar physical characteristics, it is expected that the value of the reaeration coefficient, as used in the Streeter formula, for Cheatham Pool will fall within the range from 0.05 to 0.11 at 20°C. The conclusions of this report are based on an assumed value of 0.08.

Another significant factor which requires consideration is the effect of intermittent releases from power units. Previous experience is inadequate to serve as a basis for acceptable prediction of this effect. Consideration of this situation leads to the tentative deduction that, under the low velocity conditions which will be encountered, intermittent releases of water from

power units with substantial intervening periods of no release will result in accumulation of slugs of highly concentrated wastes and that, as these slugs carry downstream, the reduction in concentration by mixing with river water will be far less than would be obtained under uniform flow conditions. To the extent this deduction is correct, average flows cannot be used as a measure of low flow regulation benefits.

As will be pointed out later, further study of the effects of intermittent flow is recommended. For the purpose of this report uniform flows have been assumed in estimating flows required with various assumed degrees of treatment.

Treatment Requirements.

1. To Maintain Dissolved Oxygen Objective.

Based on self-purification characteristics determined from observed field data, reduction in present (estimated 1952) organic waste loads at Nashville of 47 percent would be required to maintain satisfactory dissolved oxygen conditions in the Cumberland River under pre-regulated low flow conditions which could be expected to occur at least once in one year out of ten. With the same waste loading, but using a more severe low flow with an expected recurrence interval of twenty years, Nashville would have to provide 62 percent treatment.

For the expected 1965 waste load, Nashville would have to remove 66 percent of the load using the ten-year flow as a criterion, or 75 percent using the twenty-year flow.

In order to evaluate the effects of water resource developments on treatment requirements, the critical dissolved oxygen conditions have first been predicted on the basis of the same ten-year and twenty-year low flows, but with the new stream self-purification characteristics assumed for Cheatham Pool. Under these new conditions, Nashville would be required to provide 66 percent reduction of the 1952 waste load with a stream flow equal to the pre-regulated ten-year low flow, or 75 percent reduction with a flow equal to the pre-regulated twenty-year low flow. Similarly, the predicted 1965 waste load would have to be reduced 78 percent for the ten-year flow, or 84 percent for the twenty-year flow.

The above analysis has been summarized in Table C.

Approaching the problem from another angle, specified degrees of treatment have been assumed, and the flows needed to maintain satisfactory D. O. conditions have been derived.

With 35 percent reduction of Nashville's 1952 waste load, the flow required will be 1, 200 c.f.s., on the basis of the reoxygenation coefficient assumed for Cheatham Pool. With 85 percent treatment, a minimum flow of 280 c.f.s. will be required.

A similar analysis for the expected 1965 waste load at Nashville reveals that 35 percent treatment will require a flow of 1, 820 c.f.s., and 85 percent treatment will require a flow of 430 c.f.s.

The flows required for the different conditions of waste loading and treatment are summarized in Table D.

Table C. Summary of Degree of Treatment Required at Nashville for Various Conditions of Waste Loading and Flow.

Year	Nashville Estimated Pop. Equiv.	Assumed Design Flow c.f.s.	Degree of Treatment Required (1)	
			Pre-Cheatham	Post-Cheatham
1952	308,600	450 (20 yr. flow)	62%	75%
		620 (10 yr. flow)	47%	66%
		1000	Primary (2)	46%
		2000	Primary (2)	Primary (2)
		3000	Primary (2)	Primary
1965	477,000	450	75%	84%
		620	66%	78%
		1000	45%	65%
		2000	Primary (2)	Primary (2)
		3000	Primary (2)	Primary (2)

(1) Assumptions:
Temperature of river water 80° F. (critical summer period)
Oxygen deficit above Nashville 0.8 p.p.m.
Residual B.O.D. in stream above Nashville 1.0 p.p.m.
k_1 and k_2 values (at 20° C): Pre-Cheatham 0.1 and 0.15;
Post-Cheatham 0.1 and 0.08

(2) Less than 35% removal required.

Table D. Flows Required in Cheatham Pool for Various Conditions of Waste Loading and Treatment.

Year	Nashville Estimated Pop. Equiv.	Assumed Degree of Treatment	Flow Required for Post-Cheatham (1) c.f.s.
1952	308,600	35%	1200
		85%	280
1965	477,000	35%	1320
		85%	430

(1) Assumptions:
Temperature of river water 80° F. (critical summer period)
Oxygen deficit above Nashville 0.8 p.p.m.
Residual B.O.D. in stream above Nashville 1.0 p.p.m.
k_1 and k_2 Values (at 20° C.): Post-Cheatham, 0.1 and 0.08.

The flow requirements are based on an assumption of uniform flow. It is emphasized that widely varying flows with prolonged periods of comparatively little flow, although numerically equal on the average to the required uniform flow, will not give equally satisfactory results from a stream sanitation standpoint.

The foregoing flow requirements are related to a temperature of 80°F. This temperature, though not expected to prevail more than about two months in a year, is used for the purpose of determining the treatment requirements in the absence of low flow augmentation.

In the event that water is released in amounts sufficient to obviate the need for more than primary treatment, the flows indicated above will be required for a relatively short period during the summer months. During the rest of the year, with cooler temperature, water releases solely for stream sanitation could be substantially reduced and would depend on the water temperature at any time. As an example, the average water temperature at Old Hickory for the months of January and February for the years 1948 to 1952, inclusive, was 46°F. At this temperature it is estimated that 1965 waste loads reduced by primary and secondary treatment would require flows of 820 and 190 c.f.s., respectively, for adequate dilution.

2. To Maintain Bacterial Quality Objective.

A comparison of the bacterial quality of water at Clarksville under pre-regulated conditions with the bacterial quality to be expected under the new regulated conditions shows that the safety of the Clarksville water supply will depend largely on effective sewage treatment at Nashville. Reservoir operation will not eliminate the necessity of treatment to reduce bacterial pollution. The significant fact is that the highest values for the most probable number (M. P. N.) of bacteria at the Clarksville water intake are expected to occur during flows in excess of the maximum capacity of the turbines at Old Hickory. These higher flows have been common on the unregulated Cumberland River, and recent flow records indicate that they will not be uncommon under the new conditions.

BENEFITS

The analysis indicates that under pre-impoundment flow conditions treatment in excess of primary would have been required. On the basis of 1952 loads chemical treatment would have probably been sufficient. Under forecasted 1965 load conditions, biological treatment is indicated. It is considered that, if flow regulation is such that primary treatment is satisfactory for 1965 conditions at Nashville, the benefit is represented by the difference in cost between primary and secondary treatment.

In order to estimate the difference in capital cost between primary and secondary treatment, data from the Ohio River Survey Report were adjusted to a 1952 cost basis, using the Engineering News Record construction cost index. In addition, consulting engineers' cost estimates, based on final plans, in the period between 1947 and 1950 for various projects were considered. The costs were adjusted to the Nashville area on the basis of lower costs there as compared to the U.S. average. The adjusted difference in cost between primary and secondary treatment is $5.75 per design population equivalent for large projects.

In addition to saving in capital cost there would be a saving in operating cost. Studies of costs at many locations reveal a wide variation not attributable to difference in degree of treatment. Differences due to type of plant, pumping requirements, size of plant, quality of operation, and other factors, obscure the actual difference due to degree of treatment.

An analysis was made based on additional labor, power and materials and equipment for maintenance, assuming purchased power and use of the activated sludge process. On the basis of this analysis it is considered that an increased cost of $70,000 per year can be assumed for the purpose of this report as the difference in operating cost between primary and secondary treatment at Nashville, assuming 1965 loads and assuming that all wastes are subject to such treatment regardless of whether they are connected to the municipal plant.

In computing total annual charges, amortization of capital costs is taken over a period of twenty years at 2.5%.

Based on the above considerations the total annual saving of primary treatment over secondary treatment would be:

Amortization and interest	$176,000
Operating costs	70,000
Total	$246,000

There are other benefits which could be attributed to the water resources developments. Regulation of flows which would eliminate necessity for higher degrees of treatment at Nashville would also make available additional capacity for similar purposes downstream should industrial and municipal development require it. Although no tangible benefit is assigned, this feature should not be disregarded, particularly in an area such as this where industrial development is on the increase.

The benefits due to provision of an ample quantity of cooling water for the new steam plant at Gallatin are evidently quite substantial. Consideration of these benefits is not deemed to be within the scope of this report or a proper function of this office.

Allowance for benefits due to reduced treatment of wastes entering the river at Old Hickory does not appear warranted. The equivalent of primary treatment for these wastes would have maintained satisfactory dissolved oxygen levels with flows equivalent to those with an expected recurrence interval of not less than 20 years under pre-regulated flow conditions. Conceivably some allowance could be made for greater dilution of acid and toxic solutions.

DISCUSSION

This evaluation indicates the magnitude of benefits which can be obtained if flows are such that primary treatment for wastes in the Nashville area results in satisfactory water quality.

The evaluation is not conclusive with respect to stream characteristics which will prevail after impoundments are complete or with respect to effects of intermittent releases from power units as compared to uniform flows. In this connection it is well to note the status of water resources developments and provisions for pollution abatement. Water resources developments of particular significance to pollution abatement are either under construction or completed. A program directed toward provision of primary treatment of wastes is under way at Nashville. A more accurate determination of flow-pollution abatement relations can be made after present projects are completed, and should be directed toward a more thorough analysis of self-purification characteristics of the stream, effects of intermittent flow releases, and quantity of supplemental releases needed in conjunction with various degrees of sewage treatment, taking into consideration seasonal variation in temperature.

In addition to other factors the amount of supplemental releases needed for pollution abatement will be affected by the extent to which operating schedules for power releases can be modified and turbine capacities throttled to best meet flow regulation needs and, at the same time, cause

a minimum detrimental effect on power generation. The substantial benefits which could accrue to pollution abatement, should flow regulation be sufficient, warrant careful consideration of the matter.

Further investigation, study, and analysis, including stream sanitation surveys and determination of the feasibility and desirability of modifying operation for power generation and provision of such supplemental flow as may be needed are matters for consideration by interested Federal, State, and local interests.